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UCR College of Engineering- Center for Environmental Research & Technology

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CE-CERT Bus Emissions Research to Benefit School Children of California

CE-CERT research has turned into a $200 million program to reduce pollution children are exposed to while riding school buses.

The California Air Resources Board (ARB) allocated the money to replace the 74 oldest school buses still in use in the state and to replace or retrofit an additional 4,500 vehicles.

Dennis Fitz, manager of CE-CERT Atmospheric Processes Group, led a team including UCLA scientists to measure concentrations of pollutants in bus cabins and used tracer gases to determine the degree of self-pollution due to the bus's engine exhaust emissions.

"I can't even begin to describe the significant health benefits that this program will bring into California and particularly for our most precious sector of the population, our children," said ARB Chair Mary D. Nichols.

Proposition 1B, approved by voters in 2006, provides funding for the ARB Lower-Emission School Bus Program. This money will allow school districts to replace or retrofit diesel school buses in another effort to reduce diesel particulate matter emissions in California. Since established in 2000, the program has provided over $100 million to replace 600

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CE-CERT's 2007 Annual Report is available in pdf form at http://www.cert.ucr.edu/research/pubs/Annual_Report_2007.pdf or by contacting Amanda Raymer at araymer@cert.ucr.edu.

Distinguished Service Awards Presented

Elizabeth Deakin, William Johnson and Ronald Loveridge won CE-CERT's Distinguished Service Awards for 2008. The awards are given to individuals who have helped CE-CERT further its agenda of research, teaching and service.

Deakin, Professor of City and Regional Planning at UC Berkeley and Director of the University of California Transportation Center, won in the Academic Category.

She has given CE-CERT strong support in scholarship aid and research opportunities. Previous winners include William R. Pierson of Ford Motor Co., Robert Sawyer, also from UC Berkeley

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Loveridge

Johnson

Deakin

CE-CERT undergraduates Edi Rocha and Benjamin Catarino pose with the solar-powered vehicle they developed for UCR's 2008 Earth Day celebration. Rocha and Catarino are students of CE-CERT Director Matt Barth.

Vu Earns Summer Scholarship

Anh Vu won a National Science Foundation scholarship to spend the summer studying intelligent transportation systems at Osaka University in Japan. Vu, who is studying under CE-CERT Director Matt Barth, will be in Japan for three months. The scholarship comes from the NSF's Office of International Science and Engineering and is part of the East Asian and Pacific Summer Institutes program for graduate students.

1st Quarter Contracts Hit $6.3M

CE-CERT researchers won $6.3 million in new contracts and grants during 2008's first quarter.

The list was topped by a $1 million contract from the California Air Resources Board to Tom Durbin to compare various diesel fuels approved by California and by the federal government.

Charles Wyman's group won a $833,623 contract from the Department of Energy to study pre-treatment methods for biological conversion of switchgrass into ethanol as a fuel.

The South Coast Air Quality Management District awarded Matthew Barth a $500,000 contract on technical assistance for advanced, low-and zero-emission technologies and implementation activities.

The total represented one of CE-CERT's strongest quarters ever. The Center won $8.2 million in contracts for the full year of 2008, its second best annual performance.

Yee Wins National Science Foundation Graduate Scholarship

Lindsay Yee, a graduating senior who has done considerable work in CE-CERT's Atmospheric Processes Laboratory, has won a highly competitive three-year National Science Foundation Graduate Research Fellowship. Yee will pursue a Ph.D. in atmospheric studies at the California Institute of Technology.

Yee worked under Dr. David Cocker in the APL while earning a 3.9 GPA and winning the Ford Motor Co. Undergraduate Scholarship and the Jim Guthrie Undergraduate Research Competition. "Lindsay has been a top researcher in our Atmospheric Processes Lab for four years and is quite deserving of this national honor," said Cocker.

European Method for Measuring Diesel Particulate Emissions Tested by CE-CERT

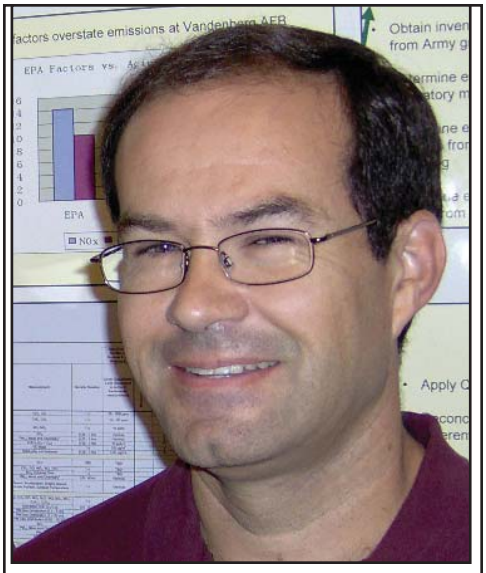
By TOM DURBIN

Regulatory limits in California and the U.S. for newer heavy-duty diesel engines are now being met with diesel particle filters (DPFs). But making measurements at these 2007 limits is challenging, especially for very low levels of particulate matter (PM). Improvements to the gravimetric method have been issued by the US EPA and in Europe for emission certification.

While the new gravimetric methods are adequate for measurements near the certification limit, accuracy will continue to be a problem at the much lower emission levels that optimized DPFs typically produce. One methodology that has shown promise for making PM measurements at these low levels is the measurement of particle number.

This methodology has been studied and developed through Europe's Particle Measurement Program (PMP), and has been shown to be 20 times more sensitive than gravimetric particle mass measurements at very low emissions levels.

The European PMP program also includes important provisions in that it focuses on the measurement of "solid" particle number and only particles that are larger than 23 nanometers (nm). These provisions allow for a more repeatable measurement since it largely eliminates nucleation particles that are smaller in size, typically volatile in nature, and



Dr. Tom Durbin leads research in the Vehicle Emissions and Fuels Group at CE-CERT. His work centers on vehicle emissions with an emphasis on particulate emissions. He is about to embark on a project for the California Air Resources Board studying biofuel emissions. Before joining the vehicle emissions group, Durbin was involved in research on renewable energy and fuel sources and advanced vehicle technologies. Durbin received his doctorate in Physics from the UCR in 1994 where the primary focus of his dissertation was the study of Si films and solid lubricants.

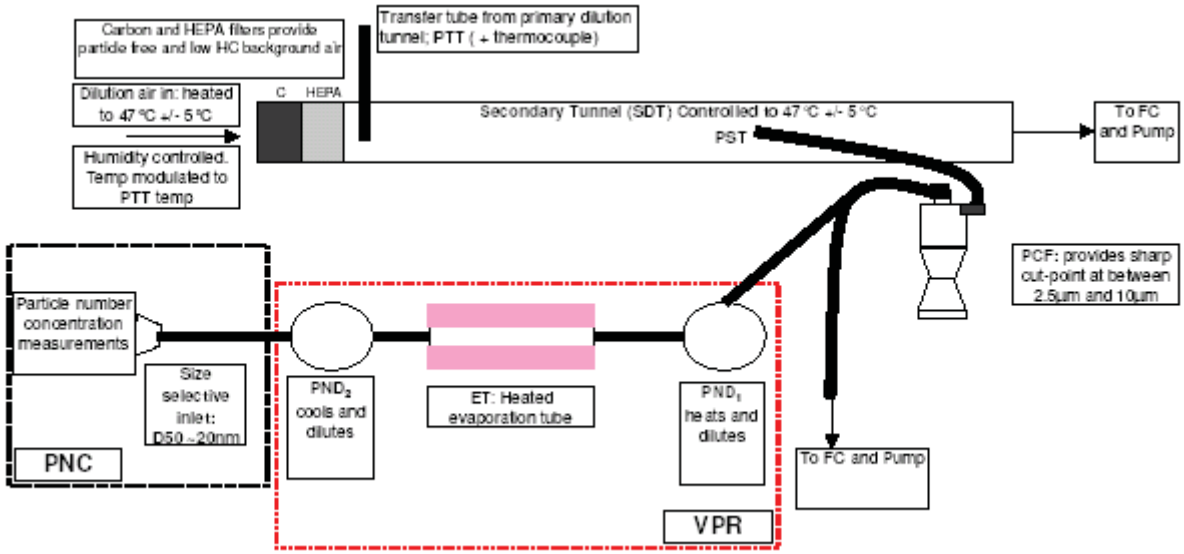


Figure ES-1: Schematic of the PMP System

less predictable than larger particles. Important factors to consider in evaluating the PMP methodology include understanding the representativeness of the particles, which are only solid and >23 nm in size, their adverse health effects, and the repeatability of the measurement.

The PMP particle sampling system is designed to measure the number concentration of solid, non-volatile particles. The system includes a hot dilution stage where the mass concentration of volatiles is reduced to help eliminate the subsequent nucleation of particles, a heated tube where volatiles are evaporated, followed by a second diluter that cools and dilutes particles to a point where no nucleation will occur.

The particles are then counted with a Condensation Particle Counter (CPC) with a 23 nanometer cut point. The PMP system was initially applied to light-duty applications in Europe, but is now being evaluated for use with European heavy-duty regulations.

This study was designed to evaluate the performance of the European PMP metrology for the measurement of solid particle number under laboratory and on-road conditions. The laboratory testing was conducted over a series of test cycle conditions at the California Air Resources Board's (CARB's) heavy-duty vehicle emissions laboratory in Los Angeles.

The laboratory is equipped with a chassis dynamometer for heavy-duty vehicles. The laboratory was equipped with a PMP dilution sampling system and a range of instruments for characterizing particle number and size. Testing was performed using a 1999 International 4900 truck equipped with an 7.6 liter International DT466E engine with a diesel particle filter (DPF).

The truck was tested over multiple iterations of an Urban Dynamometer Driving Schedule (UDDS) cycle, a 50-mph cruise, and an idle. These cycles were designed to provide a range of three different operating/load conditions.

The on-road testing was conducted using the University of California, Riverside's College of Engineering – Center for Environmental Research and Technology's (CE-CERT's) Mobile Emissions Laboratory (MEL).

The MEL contains a constant volume sampler (CVS) dilution tunnel and associated instruments that are fully compliant with regulatory require-

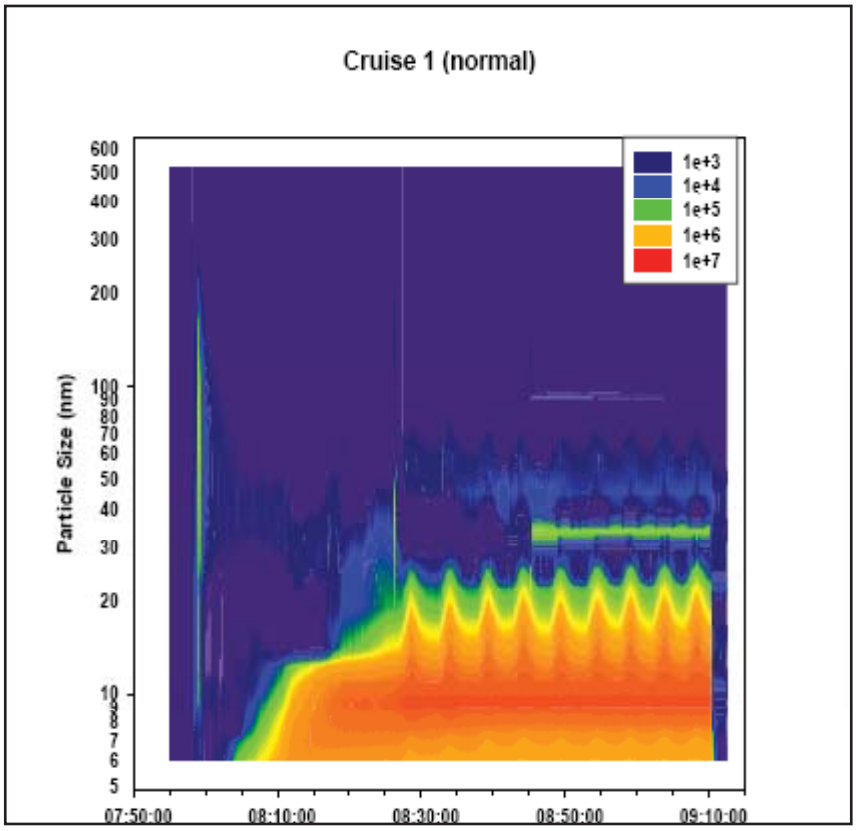


Figure ES-2. EEPS data for a 50 mph Cruise with the Corresponding Warm-up

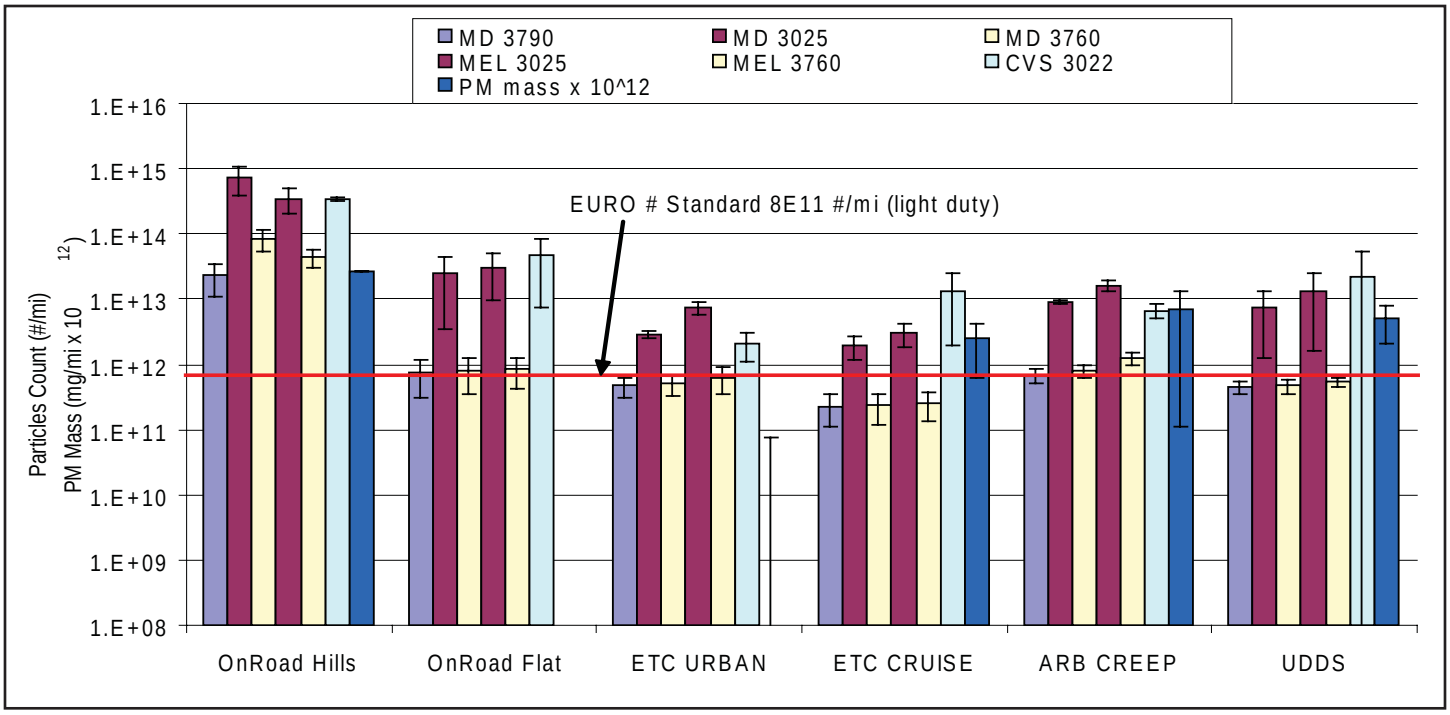


Figure ES-3. Particle Number Rate (#/mi) and PM Mass on On-Road Driving Cycles and Flow-of-Traffic Tests

ments. The CVS is housed in a 53' trailer that can be utilized on-road for in-use emissions measurements.

The MEL was equipped with two systems capable of measuring solid particles utilizing the European PMP metrology, including the system using a rotating disk dilutor and a second system based on a modified ISO 8178 partial flow single venturi fractional flow sampler.

In addition to standard PM mass measurements, a number of instruments for characterizing particle number and size were used in conjunction with these systems.

Testing was performed on-road using a 2000 Freightliner equipped Caterpillar C-15 engine with a DPF. The truck was tested over a series of standard cycles such as the UDDS, the urban and motorway segments of the European Transient Cycle (ETC), and the CARB creep cycle, as well as under typical on-road highway conditions. These cycles provide a range of operating conditions, including cycles/operation that can provide comparisons with the laboratory work above and with European efforts.

This allowed comparison of the accuracy and repeatability of the PMP and other particle measurements under conditions where variables of real-world measurements such as vibration, field deployment, ambient conditions, etc. were incorporated.

Laboratory Testing Results

The UDDS and 50-mph cruise cycles provided different distributions of particle for measurement in the laboratory testing. A plot showing the onset of nucleation is provided in Figure ES-2, where the peaks after nucleation correspond with the engine fan turning on and off. Both cycles showed a significant contribution of nucleation particles in the nucleation mode in the size distributions. The nucleation mode was typically observed once a critical temperature was reached on the post emission control device.

For the UDDS cycles, elevated particle counts and nucleation occurred during the highest speed driving portions of the cycle. For the 50-mph cruise, nucleation was initiated once a critical exhaust/DPF temperature was reached and it continued for the remainder of the cycle. For this DPF device configuration, the critical temperature for nucleation mode formation was ~310°C. It appears that the nucleation mode particles may be attributed to the conversion of SO_2 to SO_3, which is likely aided by a Pt catalytic coating on the DPF.

On-Road Testing Results

Particle number counts tested over the range

of cycles varied depending on the cycle, operating mode, measurement instrument, and sampling methodology/location.

The particle number measurements for each instrument and test cycle are provided in Figure ES-3, along with the PM mass x 10^{12}. Comparisons of particle number counts for CPCs with different size cuts showed that the instruments with the lower size cuts (3-7 nm) showed consistently higher counts than those with the higher size cut points (11-23 nm).

The 3022 CPC, which was connected to the primary tunnel, also showed higher counts than the other CPCs below the PMP system when volatile nucleation particles formed.

General Observations and Implications

Particle number offers the potential to more readily characterize emissions at the low levels currently exhibited by DPFs, which are often only a small percentage of the certification value. The advantages of particle number measurements in these respects was clearly seen for the on-road testing, but were less clear for the laboratory measurements, where longer tests produced higher/quantifiable mass levels.

It should be noted that recent studies have suggested that PM mass loadings at levels close to the current US 2007 standards are adequate to get a precise mass measurement, as opposed to the actual tailpipe PM emissions levels for optimized DPF-equipped engines.

The role of artifacts was not explored here, but can also play an important role for low level mass measurements.

The variability between the different PMP particle number counts and the PM mass depended on the cycle, sampling location and time, the specific test instrument, and other experimental conditions. For a number of testing conditions outlier events were identified using the PMP system.

It does appear that the outlier events represent real differences in particle number emissions that can be seen with the PMP, but may be masked in the mass measurement.

The nature of these outlier events, whether they are sulfate derived, due to evaporation and re-nucleation in the PMP, or from regeneration-like events in the DPF should be further explored.

Mounted in the Mobile Emissions Laboratory, this suite of instruments measures particle number in conjunction with a PMP system.

The overall combined laboratory and on-road results seem to indicate that particle number can provide a more repeatable measurement at these low levels, but that statistical techniques for the removal of outlier tests for particle number should also be considered.

Also, while the PM mass measurements have a lot of scatter at DPF tailpipe levels, the particle number measurements have outliers that can be removed using statistics.

The particle number measurements for the low cut point CPCs below the PMP system were approximately an order of magnitude higher than those for the PMP-compliant CPC and the other high cut point CPCs below the PMP system.

This means a large fraction of the solid particle from the exhaust are not being measured with the size cut of the CPC being used for the PMP protocol.

A potential disadvantage of lower the size cut for the PMP measurements is increased variability/sensitivity, which should be examined in greater depth.

Listening to a research presentation at CE-CERT's annual Board of Advisors Meeting are (clockwise from bottom center): Al Jessel of Chevron, Chung Liu of the South Coast Air Quality Management District, CE-CERT's Wayne Miller, Gene Tierney of the U.S. Environmental Protection Agency, Barry Cooper of Johnson Matthey, Tim Johnson of Corning, Michael Eaves of Clean Energy, Richard Himes of the Electric Power Research Institute and John Johnson of Michigan Technological University.

CE-CERT's 16th annual Board of Advisors meeting brings together regulators, industry representatives and academics to help the Center with its research direction.

Robert Brown of Ford Motor Co. and Kent Johnson of CE-CERT discuss Johnson's research presentation.

Ph.D. candidate Arun Raju presents his research on producing diesel from waste streams.

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school buses and retrofit another 3,800 vehicles.

The Lower-Emission School Bus Program will cover the cost to replace all 74 still-in-service pre-1977 buses and approximately one thousand 1977-1986 buses. Those replaced buses must be scrapped to comply with established guidelines. Finally, the full cost of about 3,500 retrofits will be paid under this program. Retrofits provide the greatest health benefit in emission reductions per dollar spent.

Fitz's 2003 study, sponsored by the ARB, confirmed that children can be exposed to harmful diesel emissions from the buses they ride to and from school. The same study also stated that exposure to that pollution is worse in pre-1987 vehicles, which have deteriorating engines as well as interior cabins that allow toxic emissions into the bus.

Fitz is the manager of CE-CERT's Atmospheric Processes Group.

The goal of the program is to reduce the exposure of school children to both cancer-causing and smog-forming pollution by reducing diesel particulate matter emissions from school buses.

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and Susan Hackwood, the founding Dean of UCR's Bourns College of Engineering and an early booster of CE-CERT.

Johnson, President of Johnson Machinery Co., was the winner in the Industry Category. He has been a long-time supporter of CE-CERT, especially in providing help for students and facilities for research work. Previous winners include Samuel Leonard of General Motors, Kelly Brown of Ford Motor Co. and Ben Knight of Honda R&D Americas.

Loveridge, mayor of Riverside and a board member at both the California Air Resources Board and the South Coast Air Quality Management District, won in the Government Category. Loveridge has served in city government for over two decades.

Loveridge has a long-standing concern with air quality issues and has supported CE-CERT's efforts to do effective research. Previous winners include Alan Lloyd of the California Air Resources Board, Congressman Ken Calvert and Riverside County Supervisor Tom Mullen.

UCR | College of Engineering- Center for Environmental Research & Technology
1084 Columbia Ave.
Riverside, CA 92507